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Comparative analysis of selected non-destructive methods for concrete diagnosis

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Abstract. This paper presents analysis of non-destructive testing used for determining characteristic and physical properties of a concrete. It includes described methods of 8 groups with its description and advantages and limitations. The whole content of study part is based on literature. The experimental part presents testing with use of ultrasonic tomography method.

1. Non-destructive methods

Non-destructive testing (NDT) is defined as a group of testing methods evaluating properties of a material without causing a defect. The main aim of conducting NDT is to determine the condition and integrity of material or their components without disturbing their projected functions. However, NDT are not non-invasiveness methods. Testing methods that do not influences future intended functions and usefulness are described as a non-destructive even if they are invasive to structure's integrity. Commonly known destructive testing determine the mechanical properties of material such as: compressive strength, tensile strength, yield strength etc., but indications of this properties can be indicated by NDT without exploring failure mechanism. We can distinguish semi-destructive (SDT) methods in which part of tested element is taken to the laboratory or the integrity of an element is broken, but this testing do not influences future usefulness of a structure.

NDT methods are still developing, they can indicates mechanical, chemical, electrical, magnetic, physical and even acoustical properties of tested material. They are great for determining structural defects and helping in preventing actions. The popularity of NDT increases because this methods are economical, suitable for in-situ testing and easy to conduct. The major factors that influences results obtained by NDT are depth of penetration, fusses and current information about tested structure. The understanding material's behaviour and proper application of a method ensures success in obtained results.

There are many NDT methods used in civil engineering field, they are grouped in different ways. In the fig. 1 we can notice the division of NDT methods based on literature.
Presented methods determines:

- the strength properties of a concrete,
- other features like cracks, voids, discontinuities, etc.

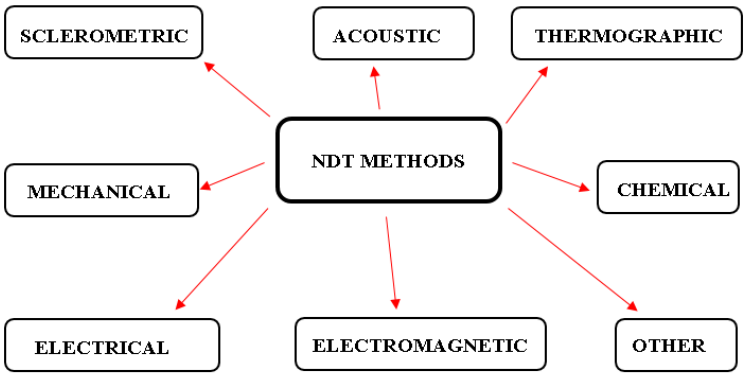

Figure 1. Division of NDT methods.

2. Sclerometric

Rebound hammer test was developed by engineer Ernst Schmidt that is why it is commonly described as the Schmidt Rebound Hammer.

Rebound hammer procedure is commonly used surface hardness method which is a correlation between strength properties and hardness of external layer of material.

Rebound hammer after contact with the concrete surface starts to record a rebound number. By referencing empirical correlations between the rebound number and properties of concrete (compressive and flexural strength) we can obtain indication of strength properties.

Figure 2. Rebound Schmidt hammer (type N) [2]

The main advantage is fast conducting the testing, obtained fast results are easy to interpretation. Method is unexpansive and suitable for testing in-situ. Unfortunately, results might be affected by many parameters like moisture content, type of aggregate, surface smoothness, age of concrete etc.

3. Mechanical methods

3.1. Probe penetration method

This method is semi destructive because it is based on penetration of the concrete. It requires driving probe with a uniform force into concrete sample and measuring the length of the exposed probe. The penetration of concrete leads to crushing and fracturing area near surface.

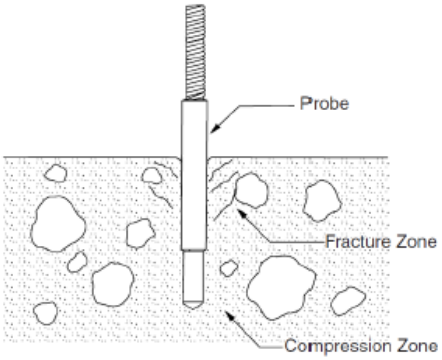

Figure 3. Scheme of concrete failure mechanism during probe penetration [1]

The main advantage is simplicity of application. Fast obtained results are easy to interpretation. The biggest limitation is damage (hole) left after testing and also a rough aggregates can affect the results.

3.2. Pull-out method

„Pull-out" determines group of methods in which we measure value of force required to pull-out earlier installed steel probe. That ultimate force describes a strength properties of the concrete.

The most commonly used is the LOK test by Kierkegarrd-Hansen, it requires insert installed in concrete structure. The force required to pull-out the insert is called "lok-strength". This force is resisted by shear and normal stresses that acts on insert installed in concrete.

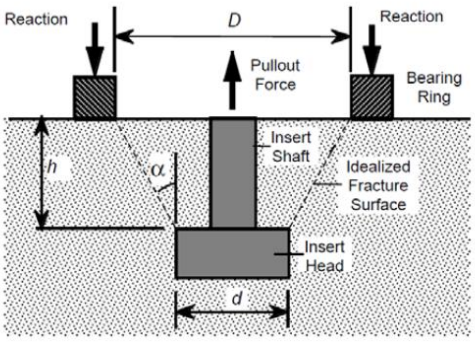

Figure 4. Schematic diagram of pull-out method [1]

The main advantage is application of that method is really quick and obtained results are easy to interpretation. Limitation is damaged area obtained after testing, also the rough aggregates can causes unreliable results.

3.3 Pull-off method

Pull-off method is tension test of concrete made in-situ. Measured force used for pull a disc bonded with epoxy or other adhesive material to concrete surface

The test set consists of bond discs, hand operated lever, force gauges and an adjustable plate. The round disc is bonded to the concrete surface with an adhesive and it is attached by a screw to the hand operated lever. Tension force is applied by the lever and measured by the force gauges when plate is pulled away from concrete surface.

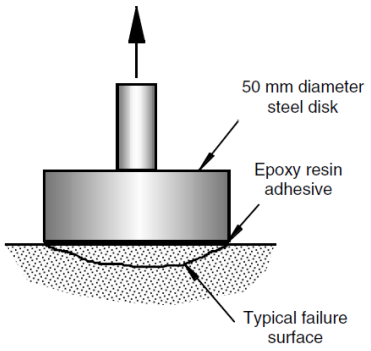

Figure 5. Schematic diagram of pull-out method [1]

The main advantage is time, method is simply in use, fast obtained results are clearly to analyse. Estimation of adhesion and tensile strength could be transformed into determining compressive strength. A limitation is the curing time needed for the adhesive (around 24hours) and human errors in surface preparation, which can leads to adhesive fail [8].

4. Thermographic methods

Thermographic methods are non-destructive tests that detects inhomogeneities and structural defects close to the surface of material. It is helpful in localization thermal bridges, defects and other places that requires renovation. The main cause of unsuccessful test is weather conditions, specially wind velocity and an air temperature.

Thermographic test covers greater areas than other test methods, results offer an indication of the percentage of imperfection area in the tested survey. The biggest limitation is high equipment cost. Testing requires special environmental properties and results varies due to weather conditions (temperature gradient, cloud cover, shaded or direct sunlight etc.). Another important limitation is the fact that the thickness and depth of defects cannot be measured. As the depth of obstruction increases, it becomes more problematic to detect.

5. Electrical methods

The main problem in concrete structure's durability is corrosion of steel. Electrical methods are commonly used to detect activity of corrosion in steel reinforcement.

Corrosion of steel is an thermodynamically and electrochemical reaction that occurs due to material characteristic of iron. Reinforcement steel in concrete starts corroding due to the moisture content, the loss of passivation and sometimes because of presence of oxygen.

5.1. The half-cell

The half-cell makes electrical interaction with the concrete by porous plug and a damped sponge. If the rebar is corroded, electrons would move from the bar to the half-cell in which electrons would be demolished in reduction reaction. Due to the connection of the voltmeter's terminals with electrical circuit, the voltmeter would show negative values.

The main advantage of this testing is portable equipment and lightweight. We can obtain active corrosion areas during testing, so results are obtained very quick. There are also few limitations. Half-cell potential method requires preparation, it must be connected to reinforcement which must be electrically connected. Obtained results do not shows corrosion rate and must be interpreted by qualified personnel.

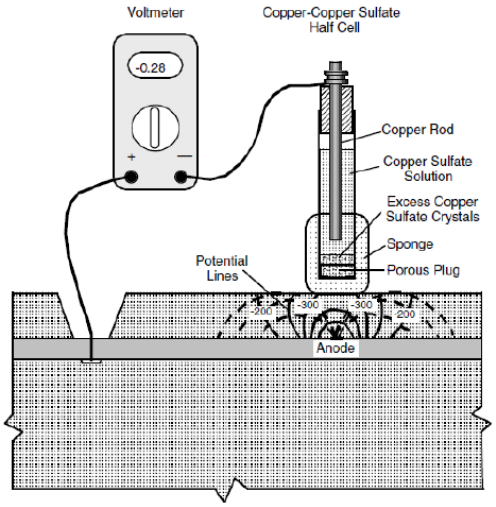

Figure 6. Schematic drawing of half-cell system [1]

6. Other methods

Due to developing of NDT methods, the range of measurement still grows. In recent years main development in optical department occurs in area of 3D methods.

Using that methods we can obtain an 3D image of the surface of structure. Analysing the image with dedicated computer programs we can get roughness parameters of surface.

It is also used with the laser triangulation methods with 3D scanners to observe surface morphology. It is used for measuring the displacements and deformation of whole structure or their parts over time. The test insists repeating scanning and comparing 3D pictures in longer intervals of time. The advantage of combination optical and laser method is that large structures can me examine quickly.

7. Chemical methods

Chemical test are used to examine the chemical properties of concrete based on material samples taken in situ. that is why, most of that methods are semi-destructive.

7.1. The pH test

Concrete as a material at the beginning of it life starts with basic pH around 13. Overtime, when concrete is exposed to weather conditions, starts to carbonate. It leads to lower pH value and can allow corrosion of reinforcing steel. When pH value is smaller than 9, there is a big probability that the corrosion of steel bars will occur.

7.2. The rainbow test

This method is based on visual comparison of the colour of concrete's surface sprayed with phenolphthalein to the litmus paper. This test does not requires taking probes, that is why this method is non-destructive. This method is used to evaluate the extent of carbonization of the layers close to the surface of concrete. Rainbow test determines the degree and a depth of carbonization.

7.3. The chloride test

It is used when we want to establish the causes of reinforced structure corrosion and it is also helpful in determining the time in which the degree of corrosion is critical and during monitoring the effects of re-alkalization processes. This method is made on site and determines the chlorides content. We can obtain the distribution and also the depth of chloride's penetration in probe cross-section. The chloride test is usually used with other methods in order to obtain the most reliable results of structure's condition.

8. Electromagnetic methods

8.1. The GPR test

The most common electromagnetic method and also the newest one is GPR – ground penetrating method.

This test allows to determine the localization of reinforcement, number and size of air voids, delamination and other material defects.

The main advantage is fast testing with use of non-contact antennas. Scanning is sensitive to the attendance of embedded metal objects and moisture There are many limitations connected with GPR testing. Cracks and other delamination are not easy to detect and congested reinforcement can stop penetration beyond the reinforcement

Proceeding testing with GPR equipment, experienced operator is required and also obtained results should be interpreted by specialist.

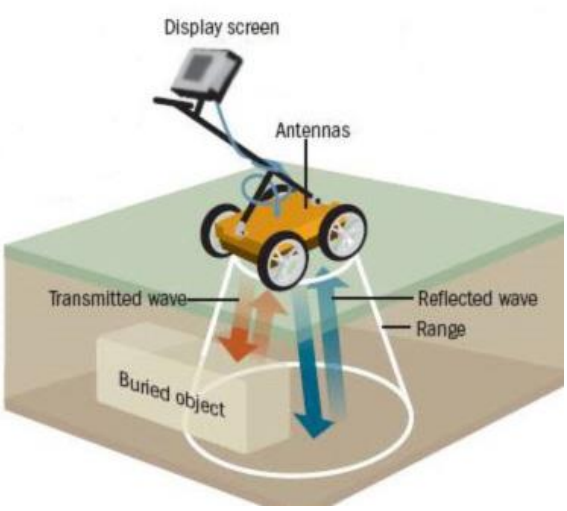

Figure 7. Exemplary scheme of GPR [http://bchazmat.com/bchazmat-services/ground-penetrating-radar-gpr/]

9. Acoustic methods

Acoustic methods are rapidly developing tests. They are good for testing material characteristics such as: voids, cracks, inhomogeneities etc. These methods are based on the propagation of sound waves. Acoustic tests presented below differ from each other on frequency of the detected and emitted signals [6-8].

9.1. The impulse response method

In the impulse response method, an elastic wave is excited by striking tested surface with a hammer. Recorded signal is amplified by the amplifier and results are formed in dedicated software as a distribution maps.

The main advantage of using this method is high speed of measuring elements and obtaining results in elements with large dimensions and simplicity in application [7].

The greater limitation is deep damages that affects obtained results. Interpretation of outcomes requires engineering skills.

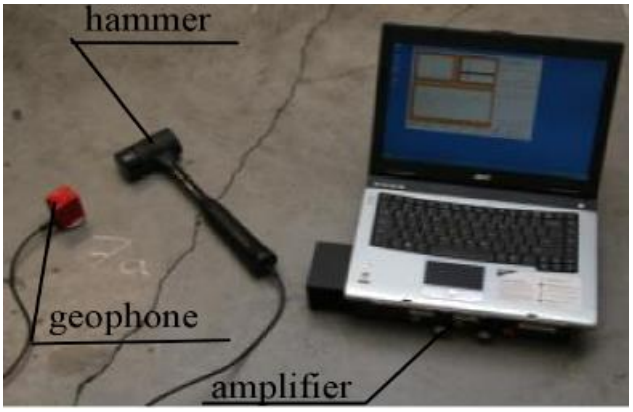

Figure 8. The impulse response method equipment [4]

9.2. The impact-echo method

The impact-echo method is used for measuring thickness of concrete and integrity. It is suitable for structures with access only from one side. A stress pulse is excited by striking concrete's surface with exciters. Excited stress wave propagate in a structure and reflects at the boundaries of different materials. The reflected wave is captured by a receiver and in dedicated software creating a charts with amplitude of spectrum which consists of relative amplitude and frequency [kHz].

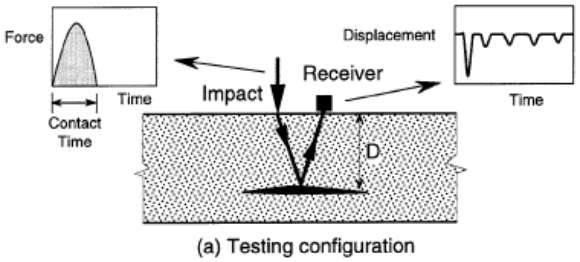

Figure 9. Scheme of impact-echo measurements [5]

The greater advantage is requirement of accessing to only one side of structure to provide testing. It allows to locate variety of defects. Impact echo equipment is easily available and does not requires coupling materials [7]. Obtained result are reliable. When it comes to limitations, beside thickness of tested structure limitation it is required to provide testing by experienced operator.

9.3. The ultrasonic tomography

The ultrasonic tomograph equipment consist of measuring antenna which is equipped with ultrasonic heads. Results are transmitted to dedicated computer software. Thanks to this testing, we can obtain a cross-sectional image of structure under the surface in a very small time. High resolution of this tomograph allows to determines flaws as small as 10 mm.

Figure 10. Scheme of impact-echo measurements [http://www.acsys.ru/eng/production/detail/a1040-mira/]

The main advantage of application this method is simplicity in use and rapidly obtained results. Another feature is the fact that we can test a big specimen having access only from one side.
There are no many limitations, obtained results should be analysed by experience and qualified staff. Due to the fact that this is new method, it is still expensive equipment

10. Experimental part

The acoustic methods are the most developing group of NDT testing, experimental part presents conducted study of ultrasonic tomography method.

10.1. Probe no. 38

10.1.1. General information.

Probe number 38, presented in the pictures below has visible three holes with different diameter. All holes were empty inside, but as we can see on picture below, the biggest one has coat made of polystyrene (Styrofoam).There were no additional information about foreign insertions.

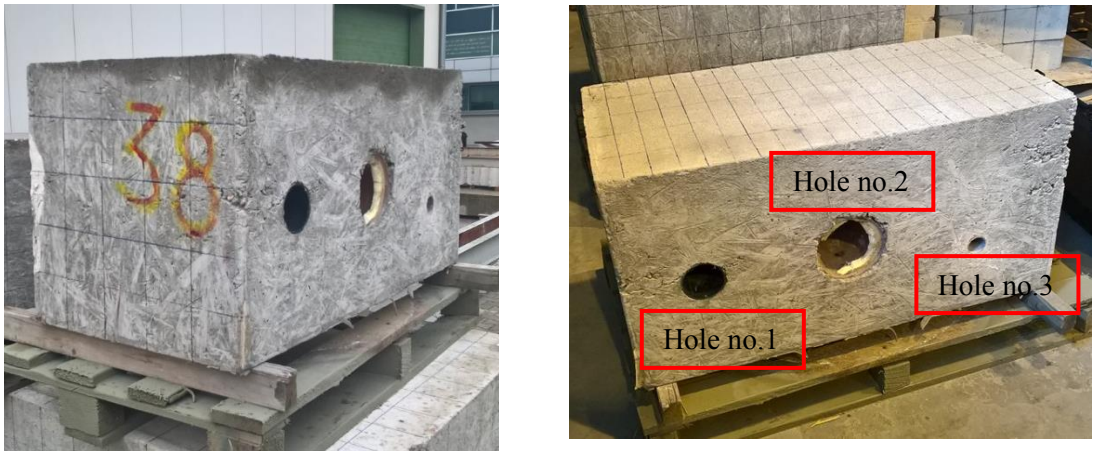

Figure 11. Picture of probe no. 34 and a zoom to longitudinal crack on it.

Tested probe with dimensions 500x 500x1000 mm was tested as in the scheme below. A mesh on top side has dimension of one cell 100 x 100 mm. Tomograph with every single scan was moved with a distance of half of a cell – 50 mm.

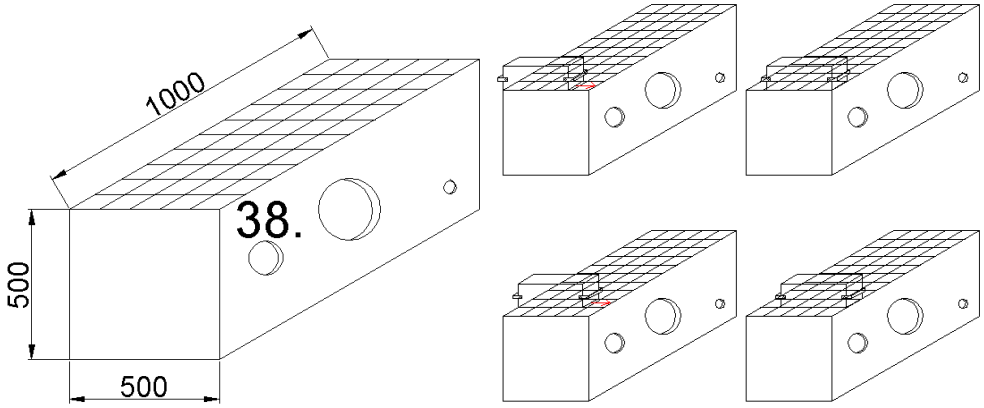

Figure 12. Picture of probe no. 34 and a zoom to longitudinal crack on it.

10.1.2. Results

From scanning only top side of a specimen we obtain 15 rows – 5 images in one column (1.1; 1.2; 1.3; 1.4; 1.5). In all we obtain 75 scanning images, rows are marked with X, and column with Y. This marks allows us to localize scanned images and its defects.

Obtained images shows already known holes in a specimen. Reflection at the depth of 500 mm confirms the depth of tested probe. In figures below there are few exemplary images showing reflection of propagated wave in the place of all three holes.

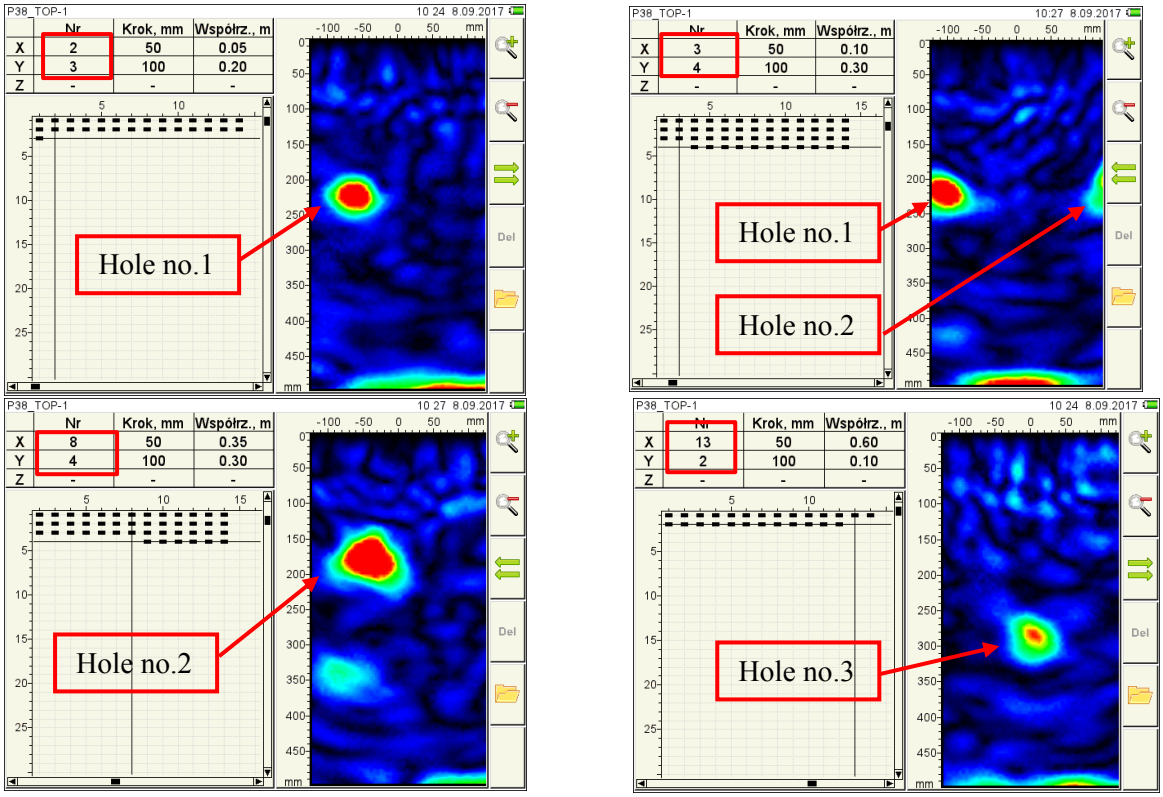

Figure 13. Scanning images obtained from testing top side of a specimen no. 38

At the image 2-3 (Fig.13) we can see strong reflection at the depth around 225 mm – it is the top edge of hole no.1, we also can see the reflection at the depth of 500mm – bottom of a specimen.

In the image 3-4(Fig.13) it is clearly shown two holes at one image, it means that tomograph in the position 3x – 4y measured area in which the spread wave reached two holes.

The image 8-4(Fig.13) shows only the hole no.2. Depth of the hole no. 2 is equal around 175 mm depth. In this image we can also notice the reflection at the depth of 500 mm – bottom of tested specimen.

On the last exemplary image 13-2. (Fig.13) we can detect hole no. 3. The last foreign insertion is localized at the depth around 275 mm.

11. Conclusions

Current concrete structure's condition can be more precisely diagnosed with the use of presented methods. Tested parameters are connected with durability of structure, but measuring the prediction of durability is more complex problem.

The main advantage of NDT methods in their great capability to provide testing in situ. Results of presented methods indicate unknown or hidden defects which can be useful data for repairing process. Combination of different presented NDT method can provide to better evaluation of structure's current condition. Non-destructive methods of concrete testing gaining acceptance in evaluating material integrity.

Obtained scanning images shows real localization of 3 holes inserted in a probe. We obtain detailed information about depth of tubes and depth of tested specimen. Results are confirming the reality.

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